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THE TWO AXIS MOTION SIMULATOR FOR THE LARGE SPACE SIMULATOR AT E.S.T.E.C.

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ABSTRACT

The Large Space Simulator at ESTEC has recently been equipped with a Motion Simulator capable to handle test articles of 5 tons mass and having a volume of 7m in diameter and a length of 7m. The Motion Simulator has a modular set-up, it consists of a Spinbox as basic unit on which the test article is mounted and which allows continuous rotation (spin). This Spinbox can be used in two operational configurations:

- Spin axis vertical to 30° inclination when mounted on a Gimbalstand;
- Spin axis horizontal when mounted on a Turntable - Yoke combination.

The Turntable provides rotation within ± 90°. This configuration allows to bring a test article in all possible relative positions vis-à-vis the sun vector (which is horizontal in this case).

The Spinbox allows fast rotation between 1 - 6 rpm or slow rotation between 1 - 24 rot./day as well as positioning within ± 0.4° accuracy. The Spinbox is provided with a slipring having considerable transmission capacity, totally some 480 direct channels ranging from low level DC (thermocouples) till UHF and power channels with an overall rating of 310 Amps in total. Additional multiplexing of thermocouple lines is possible.

The Motion Simulator in both configurations is shrouded so that no warm spots are visible from the test volume. It is specially designed for quick installation and removal. Provision is made for a later implementation of a Levelling System allowing precise levelling when tested satellites are carrying heat pipes.

INTRODUCTION

In order to give the new Large Space Simulator at ESTEC the full operational capabilities it was necessary to install an appropriately large Motion Simulator. This facility should be capable to accept test articles in size and mass corresponding to the possibilities of the Space Simulator. In addition it should provide the highest possible flexibility, it should allow simple installation and removal and stay within minimum costs.

In early 1985 prestudies began and the technical requirements were defined. A modular concept was chosen. The basic unit is the Spinbox on which the test article is mounted via a test adaptor. It allows continuous rotation at normal spinning speed as well as at very low speed for the simulation of geostationary orbits. The Spinbox is provided with a Slipring having considerable transmission capabilities for electrical signals and power. Altough the Spinbox is designed to operate in any position in respect to the gravity vector, two basic configurations have been chosen as follows:

- o Spin axis vertical to 30° inclination when mounted on a Gimbalstand (Figures 1 and 5);
- o Spin axis horizontal when mounted on a Turntable - Yoke combination (Figures 2 and 6).

In the latter configuration the Turntable can be positioned within ± 90° thus allowing to bring the test article on the Spinbox in any relative position vis-à-vis the sun radiation. Both configurations are built up on the existing seismic structure inside the vacuum chamber. A shroud subsystem exists for both configurations shading the test article from unwanted thermal radiation.

The facility performance requirements are summarized in Tables I and II. Contracts for design and manufacture of the 4 main subsystems namely the Spinbox, the Turntable, the Gimbalstand and the Slipring were placed in late 1985/early 1986; the procurement of the other items, the integration at ESTEC, the system engineering and management has been provided by the ESTEC engineering services.

The installation of the Motion Simulator was completed in December 1987, the acceptance test followed in January 1988, the acceptance review took place in February 1988. Immediately after that, a flight unit of an ESA Astronomy satellite (Hipparcos) was installed on the Motion Simulator and the first operational test using this equipment was successfully completed one month later.

DESCRIPTION OF THE DIFFERENT ITEMS OF THE MOTION SIMULATOR

SPINBOX

A schematic cross-section of the Spinbox is given in Figure 3. The hollow shaft provides room for the installation of the Slipring including the necessary clearance for the cooling air around the Slipring. The bore in the shaft has a diameter of 328 mm. Since the interior of the Spinbox is at ambient pressure, a rotary seal consisting of 3 individual graphite embeded teflon lip-seals is installed.

The first interseal volume after the ambient is backed up by a vacuum line, the pump of which is installed under the vacuum chamber. Also the second interseal volume is connected to a vacuum line which, however, is only pumped in emergency cases. The shaft is guided by means of a cross-roller bearing which came out in a preceeding detailed study as best compromise between deformation requirements and volume constraints. The bearing is inside the air compartment of the Spinbox and has the necessary gearing on its inner ring.

It is driven via a pinion on the cyclodrive by two servo motors, one for fast and one for slow motion. A clutch separates the slow motor from the cyclodrive when the fast motor is in operation. A break prevents rotation of the shaft when the motors are stopped.

All the potentional high energy dissipating units: motors, cyclodrive, bearing and seal are connected to a water cooling system. In addition, cooling air circulates in a controlled way inside the Spinbox. This air flow backed up by the electrical heaters also keeps the Spinbox at a sufficient temperature level in cold test phases to avoid condensation. A dome on the spacecraft side of the Spinbox is provided with the necessary vacuum feedthroughs for the signal and power lines. It is noticable that the dome on the spacecraft side as well as the backcover of the Spinbox are easily interchangeable. This was already necessary during the first operational test with the Motion Simulator as will be explained in the paragraph of the Slipring.

A final remark shall be made on the rotary seal. Because initial doubts were existing regarding the reliability and lifetime of friction based seals, a study was performed about the feasibility to install a magnetic seal. Altough the magnetic seal has an ideal performance, high reliability and practically unlimited lifetime it was refrained from the utilisation of this type of seal because the pressure difference acting on the seal in combination with its diameter (600 mm) required a gap clearance between shaft and housing at the seal so small that it was not practical for manufacturing and could not be safely maintained with a loaded Spinbox.

YOKE

For the configuration with horizontal spin axis the Yoke is interfacing to the Spinbox on the top side and to the Turntable on the bottom side (see Fig. 2). The Yoke is a box type structure of high torsion and bending stiffness. The box interior is vented to the vacuum. A heater system keeps the Yoke at a certain minimum temperature. On both sides of the Yoke runs a tube of 210 mm diameter. These tubes are connected to the air compartment of the Spinbox on one side and to a central air compartment in the lower part of the Yoke which in turn mates to the interior of the Turntable on the other side. One tube contains all Slipring lines, the other contains all Spinbox housekeeping lines. The two tubes also serve as outflow for the Spinbox cooling air.

TURNTABLE AND ROTARY CABLE GUIDING DEVICE

A schematic view of the Turntable and the rotary cable guiding device is shown in Figure 4. The Turntable is built up of a massive tubular support structure. Its inside is at atmospheric pressure. The lay-out of the drive is similar to that of the Spinbox. For reasons of keeping sparepart costs down the following elements are identical to those of the Spinbox: main bearing, fast and slow motor and cyclodrive. The rotary seal is also of the same build-up as on the Spinbox only the seal diameter is considerably larger (1390 mm). Also in this case the main bearing is in the air compartment.

Its inner rotating ring is fixed to a circular plate which interfaces to the Yoke. In its centre this plate has a large circular hole allowing the two cablebundles coming from the Spinbox through the tubes of the Yoke to pass. The Turntable rests on a massive baseplate which is fixed to the seismic structure. The same baseplate is also required for the Gimbalstand and therefore normally stays in the chamber. It is connected via a tube of 570 mm diameter to the bottom flange of the chamber. The interior of this tube again is at ambient pressure. Inside this tube is another centric rotating tube placed which is resting on a system of rollers supported by the baseplate. It is driven via an upper mating tube fixed to the rotating part of the Turntable.

The interspace between the outer and the inner tube carries the (stationary) housekeeping lines of the Turntable, the inner tube carries the 2 cable bundles coming from the Spinbox. The inner (rotating) tube protrudes through the chamber bottom flange into the room under the chamber. There it mates to the rotary cable guiding device located under the vacuum chamber.

This rotary cable guiding device is necessary to assure an orderly bending of the 2 cable bundles coming from the Spinbox when the Turntable is rotated. It consists of two large chains supporting the two cable bundles. The chains are guided in a controlled manner throughout the full operational range of the Turntable.

GIMBALSTAND

The Gimbalstand consists of a massive framework supporting the Spinbox. The inclination of the Spinbox is provided by a drive unit mounted on one side of the Gimbalstand. The drive unit is a sealed compartment at ambient pressure. It houses the servo-controlled drive motor acting via a wormgear onto the Gimbalstand inclination axis.

In the case of the Gimbalstand configuration the two cable bundles coming from the Spinbox are routed via 2 x 2 vacuum tight flexible umbilicals ending on their lower end to a dome located under the Gimbalstand and mating to the baseplate. By this means a direct air connection of the Spinbox and the facility exterior is provided as has been realised in the Yoke configuration.

The Gimbalstand also serves as a maintenance stand for the Spinbox outside the chamber. In this mode 360° rotation is possible. In order to avoid an override over the 30° position when located in the chamber (which would destroy the umbilicals and LN_2 lines) special safety devices have been installed. Below the Gimbalstand a room of 360 mm is left free allowing the later implementation of a levelling system for accuracte levelling when tested satellites are carrying heat pipes.

SLIPRING

In the baseline configuration the Slipring has an overall length of 1080 mm and a diameter of 302 mm. It consists of totally 54 discs carrying up to 12 rings on both sides. A controlled air stream flows over the outside of the Slipring maintaining a controlled temperature environment and carrying away excessive heat. An inside bore of 75 mm diameter provides room for other rotary feedhroughs e.g. waveguides.

During the first operational test a special rotary feedhrough for two venting lines leading to the satellite under test had to be installed. In all these special cases the baseline length of the Slipring will be exceeded. It was therefore necessary to foresee a possibility to extend the Spinbox on the satellite side as well as on the opposite side providing the necessary additional room. It is foreseen to equip the Slipring in the future with a digital multiplexing device for thermocouple signals.

SHROUD SYSTEM AND MOTION SIMULATOR THERMAL CONTROL

In order to minimise heat exchange with the environment all parts of the Motion Simulator located inside the vacuum chamber are covered by easily removable and remountable multilayer insulations. To prevent excessive cooling down in cold test phases, electrical heater foils are installed at critical locations. Spinbox and Turntable have in addition their own internal water and air temperature control systems which are microprocessor controlled from the control console.

All parts of the Motion Simulator inside the chamber are covered with flat shrouds. In the configuration Gimbalstand, the Spinbox shroud not only shields the Spinbox but also serves as protection of the test article from thermal radiation of the Gimbalstand and the unprotected areas of the seismic structure.

The Yoke carries two shrouds: one on its inclined middle part and a horizontal shroud on its lower part. In order to allow the Turntable rotation, the in and outgoing LN_2 lines to the Yoke shrouds are passing via a spiral type up and offwinding device which is attached to the under side of the Yoke lower shroud. All shrouds are connected in serie in order to assure uninterrupted LN_2 flow.

DATA, POWER AND HOUSEKEEPING TRANSMISSION LINES

The lines coming from the test article enter the rotating part of the Spinbox via vacuum feedthroughs located on the dome. In both configurations they pass from there on entirely in ambient environment to the outside of the vacuum chamber. The housekeeping lines stay entirely in ambient environment on their way to the facility exterior. This constitutes a considerable costsaving factor taking into account the prices for vacuum feedthroughs and vacuum suitable cabling. Furthermore, a great number of additional leak sources are eliminated. Connectors for the Slipring lines and the Spinbox housekeeping lines are located at the Spinbox and below the chamber before entering the rotary cable guiding device.

CONTROL CONSOLE

A Control Console located in the control room allows to control and monitor all active and passive parts of the Motion Simulator. For operation under ambient conditions of the Spinbox, Turntable or Gimbalstand in the storage / maintenance area and inside the chamber a local panel is provided which can be connected at test floor level and storage floor level. When this local panel is connected it is impossible to operate the Motion Simulator from the Control Console in the control room.

HANDLING AND STORAGE HARDWARE

Due to the complexity of the system and the requirement of quick installation and removal a substantial amount of special hardware had to be provided.

TABLE I.- MOTION SIMULATOR PERFORMANCE DATA

GENERAL CHARACTERISTICS

o	Test volume	: 7000 mm diameter
o	Max. test specimen mass	: 5000 kg
o	Max. Moment of Inertia $I_x = I_y = I_z$	: 8000 $kg.m^2$
o	Max. unbalance	: 200 kg.m
o	Max. overall leakrate	: $1,5 \cdot 10^{-2}$ mbarl/sec

SPINBOX

o **FAST MOTION**

Continuous rotation (both directions)

-	Velocity	: 1 - 6 rpm
-	Velocity accuracy	: ± 3% of selected speed
-	Max. acceleration/deceleration	: ± 1,0 rad/sec^2

o **SLOW MOTION**

Continuous rotation (both directions)

-	Velocity	: 1 - 24 rot/day
-	Position accuracy	: ± 0,4°

o **POSITION MODE**

Rotation in both directions

-	Speed	: 30° - 60°/min
-	Position accuracy	: ± 0,4°

TURNTABLE

POSITION CONTROL ONLY

-	Rotation angle	: ± 90°
-	Position accuracy	: ± 0,4°
-	Positioning velocity	: max. 60°/min
-	maximum angular acceleration/ deceleration	: ± 1.0 rad/sec^2

TABLE II.- MOTION SIMULATOR PERFORMANCE DATA (cont'd)

GIMBALSTAND

- Rotation angle : Vertical to 30° inclination
- Position accuracy : ± 0,1°
- Position velocity : 1 - 60°/min
- Max. angular acceleration/deceleration : ± 1,0 rad/sec^2

SLIPRING CHANNEL OVERVIEW

	TYPE	NO. OF CHANNELS	NO. OF SEPARATE SHIELDS	NO. OF GROUNDINGS
BASELINE:	Low level	216	12	
	1 Amp/100V D.C.	144	8	4
	5 Amp/100V D.C.	33	3	
	100 KHz	60	60	
	10 MHz	20	20	
	VHF	8		
	UHF wide band *	2		
OPTION :	Waveguide	2		
	UHF narrow band	2		
	TOTALS	485	103	4

* Replaced by UHF narrow band for option.

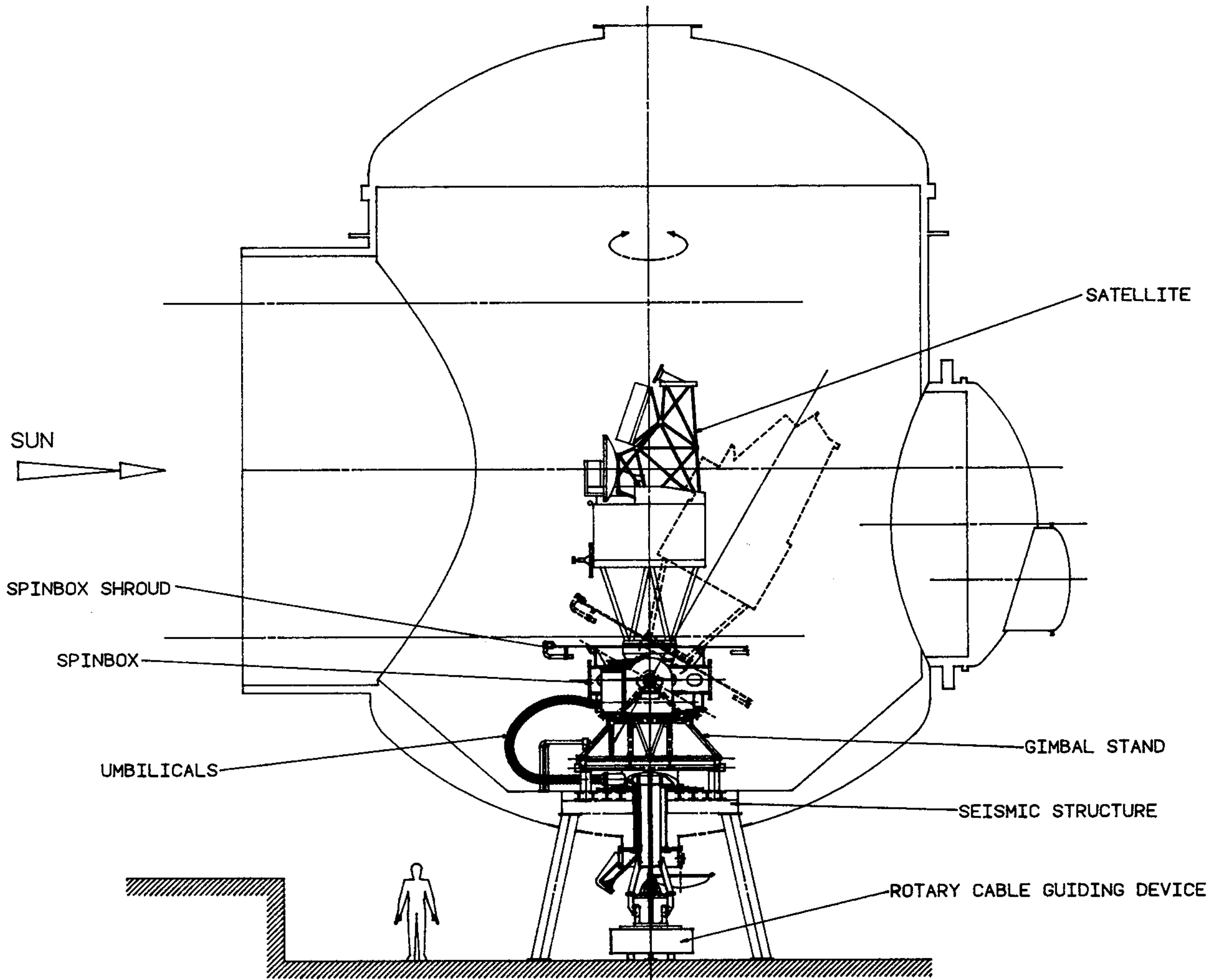

FIG. I - MOTION SIMULATOR VERTICAL CONFIGURATION

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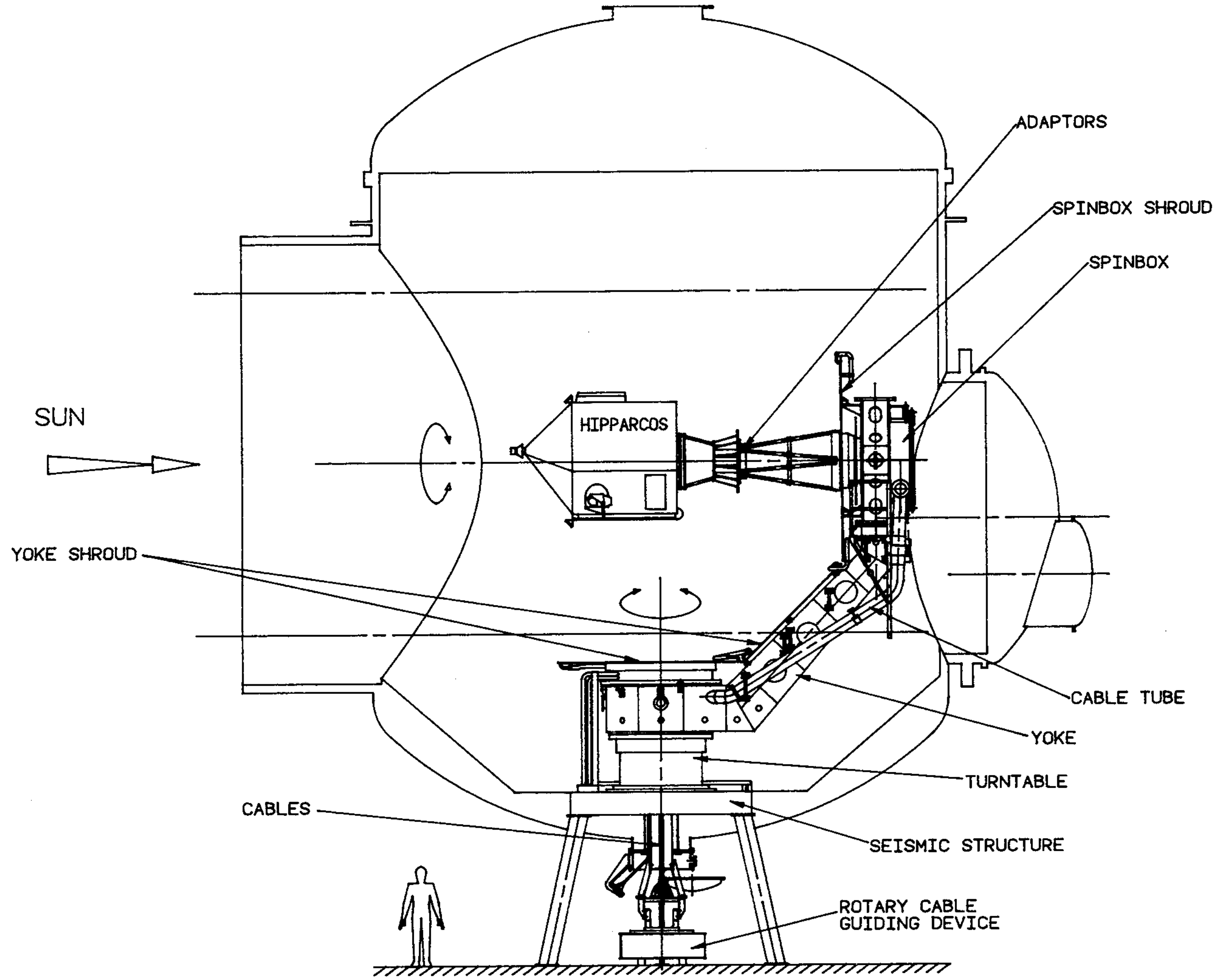

FIG.2 - MOTION SIMULATOR HORIZONTAL CONFIGURATION

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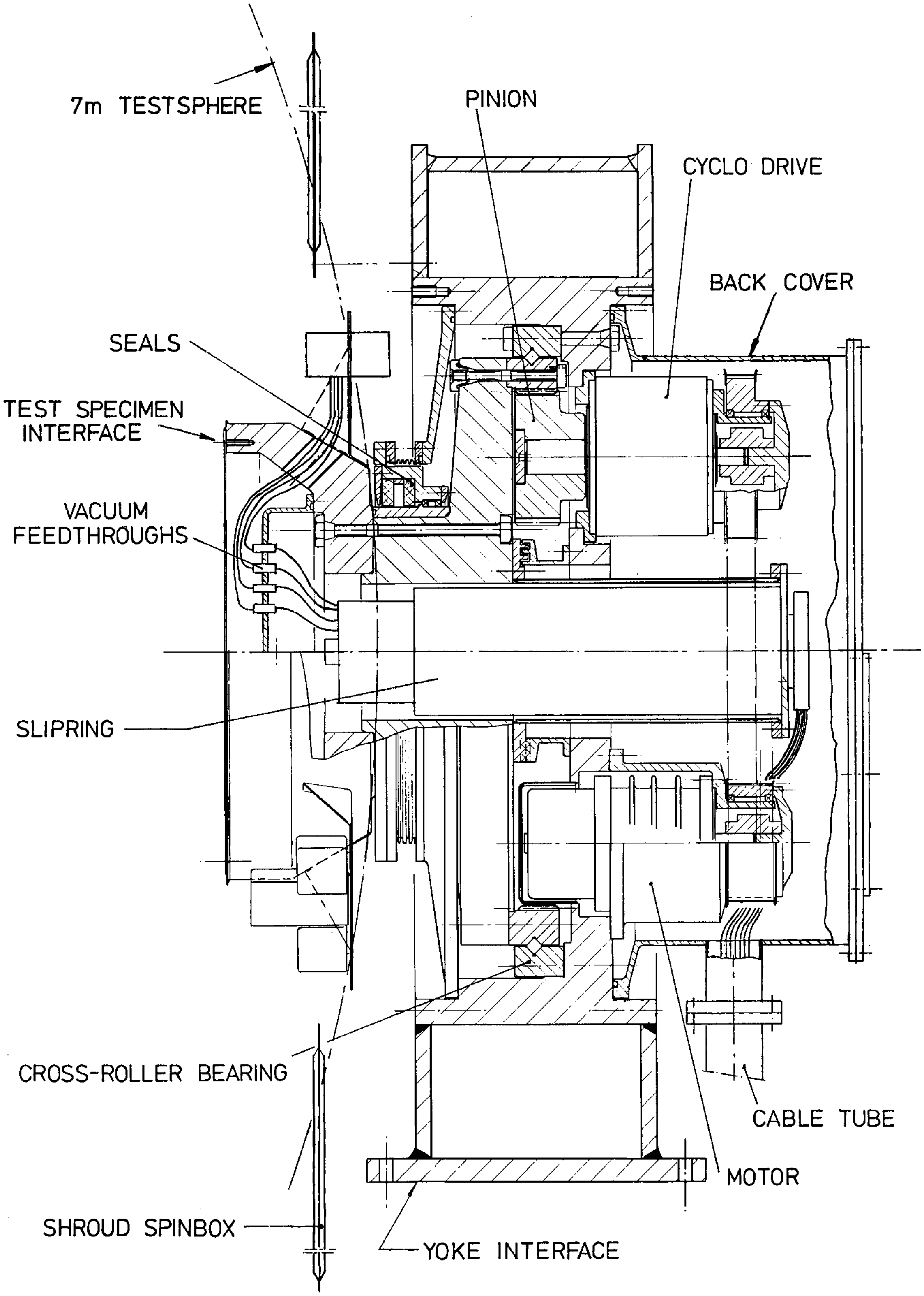

FIG. 3 SPINBOX SCHEMATIC OVERVIEW

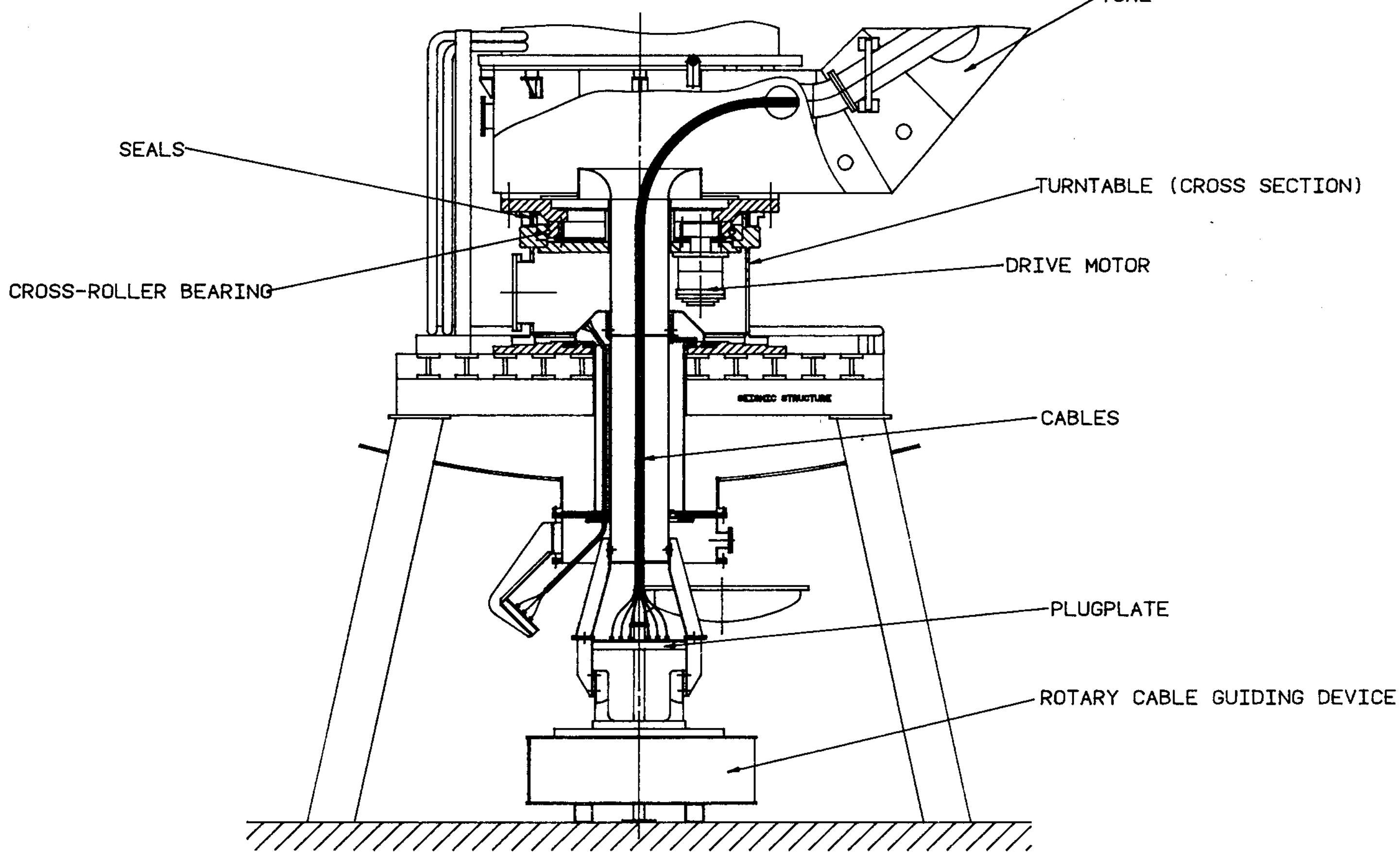

FIG.4 - TURNTABLE AND ROTARY CABLE GUIDING DEVICE/SCHEMATIC OVERVIEW

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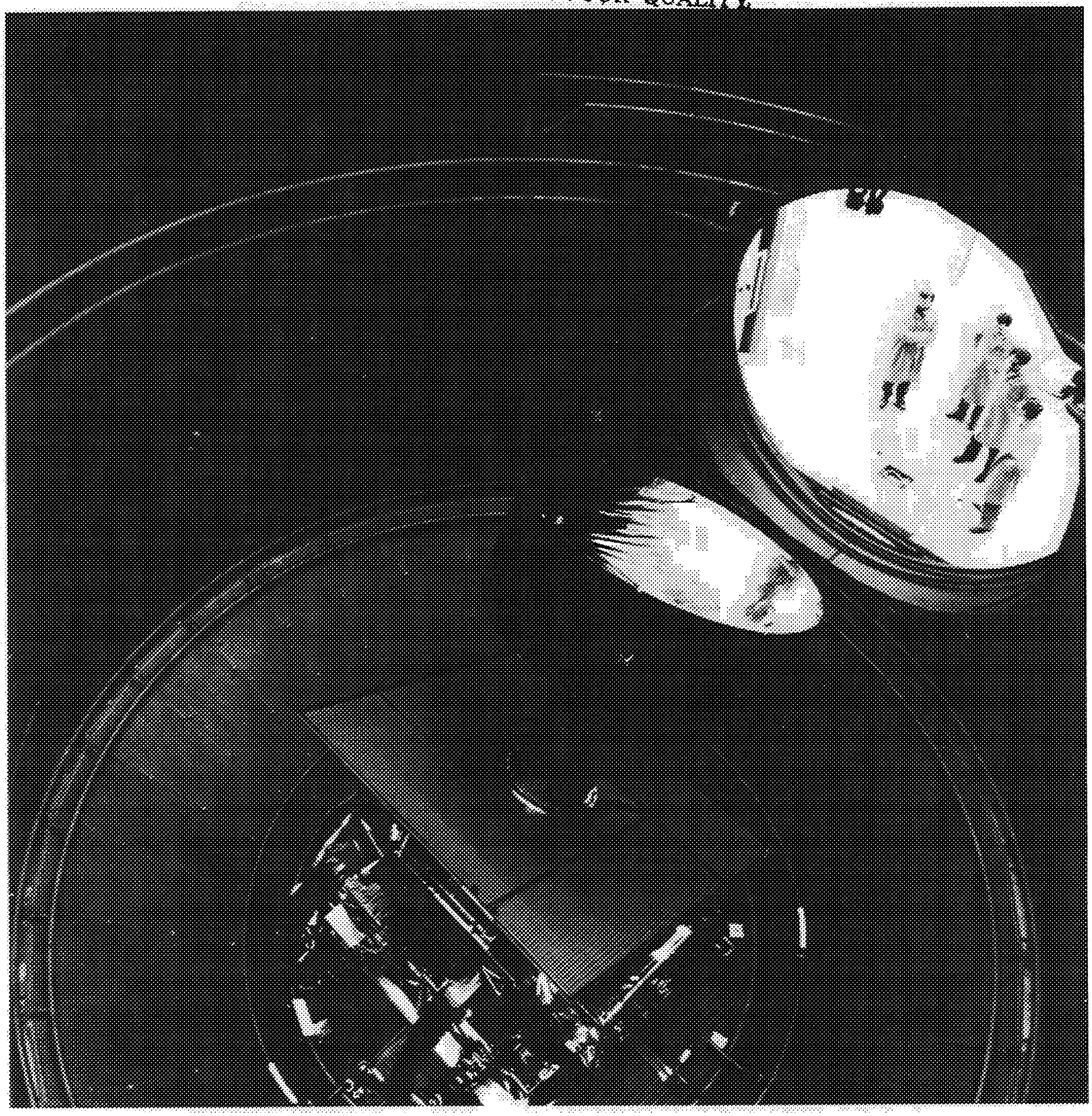

FIG. 5 - MOTION SIMULATOR IN VERTICAL SPIN AXIS CONFIGURATION DURING ACCEPTANCE TEST. SPIN AXIS 30° TILTED.

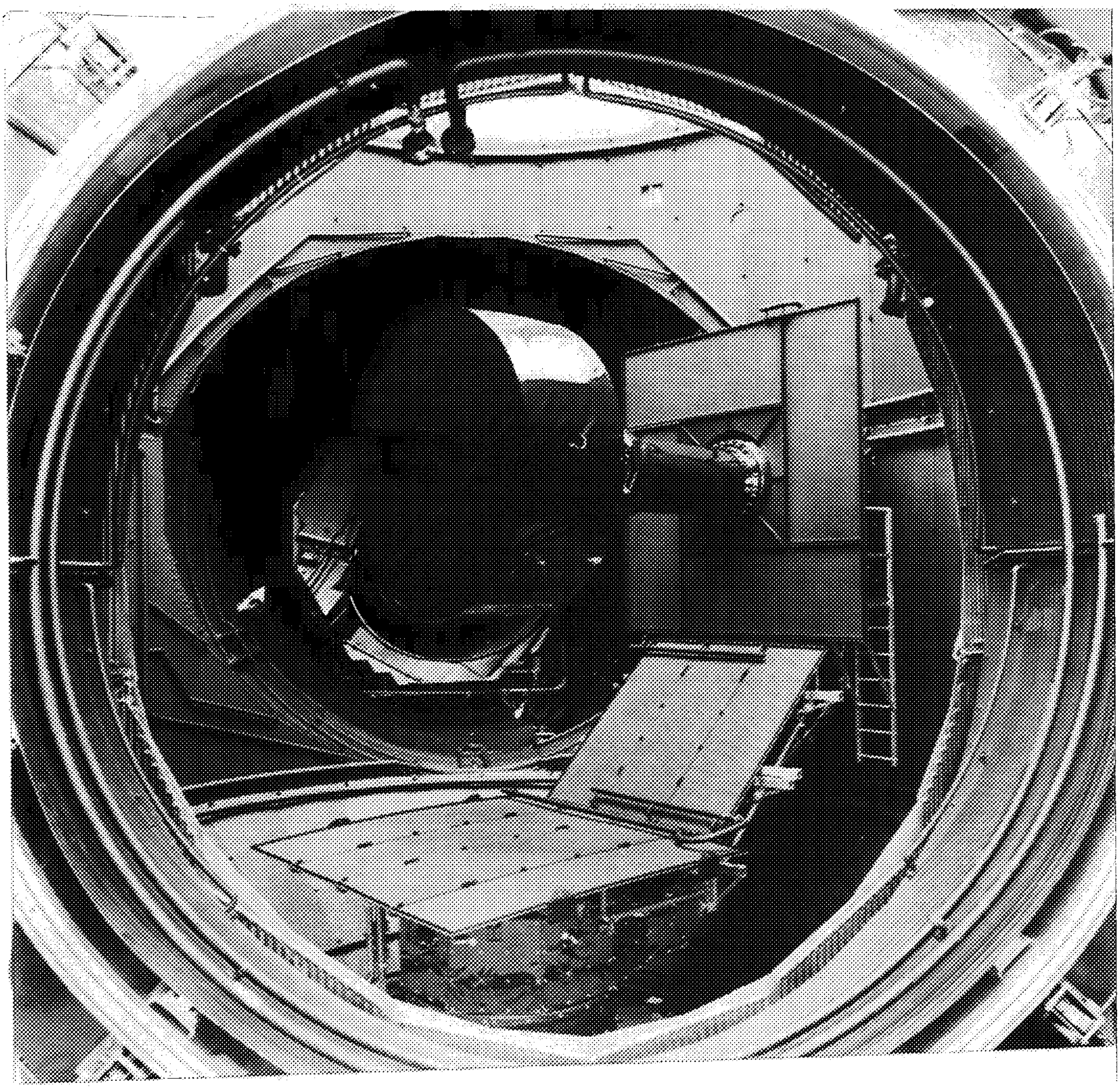

FIG. 6 - MOTION SIMULATOR IN HORIZONTAL CONFIGURATION
DURING ACCEPTANCE TEST.

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